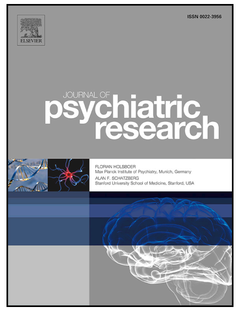
DOI:
10.1016/j.jpsychires.2018.11.004

Accepted Manuscript



Does exercise improve sleep quality in individuals with mental illness? A systematic review and meta-analysis

Oscar Lederman, Philip B. Ward, Joseph Firth, Christopher Maloney, Rebekah Carney, Davy Vancampfort, Brendon Stubbs, Megan Kalucy, Simon Rosenbaum

PII: S0022-3956(18)30852-5

DOI: https://doi.org/10.1016/j.jpsychires.2018.11.004

Reference: PIAT 3497

To appear in: *Journal of Psychiatric Research*

Received Date: 18 July 2018

Revised Date: 1 November 2018

Accepted Date: 2 November 2018

Please cite this article as: Lederman O, Ward PB, Firth J, Maloney C, Carney R, Vancampfort D, Stubbs B, Kalucy M, Rosenbaum S, Does exercise improve sleep quality in individuals with mental illness? A systematic review and meta-analysis, *Journal of Psychiatric Research* (2018), doi: https://doi.org/10.1016/j.jpsychires.2018.11.004.

Journal of Psychiatry research

Does exercise improve sleep quality in individuals with mental illness? A systematic review and meta-analysis

Oscar Lederman[1,2*], Philip B Ward[3,4], Joseph Firth[5,6], Christopher Maloney[2], Rebekah Carney[7], Davy Vancampfort[8,9], Brendon Stubbs[10,11,], Megan Kalucy[3] & Simon Rosenbaum[,3,12]

[1]Keeping the Body in Mind Program, South Eastern Sydney Local Health District, Sydney, Australia

[2]School of Medical Science, UNSW Sydney, NSW Australia

[3]School of Psychiatry, UNSW Sydney, NSW Australia

[4]Schizophrenia Research Unit, Liverpool Hospital and Ingham Institute of Applied Medical Research, Liverpool, NSW, Australia

[5]NICM Health Research Institute, University of Western Sydney, Sydney, Australia

[6]Division of Psychology and Mental Health, Faculty of Biology, Medicine and Health, University of Manchester, United Kingdom

[7]Youth Mental Health Research Unit, Greater Manchester Mental Health NHS Foundation Trust, United Kingdom

[8]KU Leuven Department of Rehabilitation Sciences, Tervuursevest 101, 3001 Leuven, Belgium

[9]KU Leuven, University Psychiatric Center KU Leuven, Leuvensesteenweg 517, 3070 Kortenberg, Belgium

[10]Physiotherapy Department, South London and Maudsley NHS Foundation Trust, Denmark Hill, London SE5 8AZ, United Kingdom

[11] Department of Psychological Medicine, Institute of Psychiatry, Psychology and Neuroscience, King's College London, De Crespigny Park, London, Box SE5 8AF, United Kingdom

[12] Black Dog Institute, Randwick, NSW Australia

*Corresponding author: Oscar Lederman, Bondi Junction Community Health Centre, SESLHD Mental Health, 26 Llandaff St Bondi Junction, Australia Tel.: +61 (02) 9366 8610; Fax: +61 (02) 9387 1070.

Email: oscar.lederman@health.nsw.gov.au

Abstract

People living with mental illness often experience poor sleep quality compared to the general population. Poor sleep quality exacerbates symptoms of mental illness and contributes to increased physical comorbidities. Exercise has been shown to be an effective non-pharmacological treatment for managing poor sleep in the general population. Little is known regarding the efficacy of targeted exercise interventions for improving sleep quality amongst individuals with a mental illness. We conducted a systematic review and meta-analysis of randomised controlled trials (RCTs) examining the impact of exercise on sleep quality in people with mental illness. Major electronic databases were searched from inception until June 2018 for exercise-based RCTs that included either subjective and/or objective measures of sleep quality in people with severe mental illness (SMI). Eight RCT's were included in the meta-analysis, involving use of a range of exercise modalities in people with SMI diagnoses. Overall, exercise had a large statistically significant effect on sleep quality (hedges g = 0.73, 95% CI; (0.18, 1.28), p-value = 0.01; N = 8, n = 1,329, I^2 = 91.15%,). The beneficial effect of exercise on sleep quality outlined in this study highlights the important role exercise has in improving health outcomes for people living with mental illness. Further research is required to determine the efficacy of exercise on sleep in people experiencing a psychiatric illness and to explore the effects of exercise intervention elements such as modality, frequency, intensity and delivery settings.

Key words; mental illness, depression, sleep, physical activity, exercise, systematic review

1. Introduction

Sleep is fundamental to human health (Chen et al., 2006) and serves a range of essential functions throughout the lifecycle including brain development, cognitive processing and performance including memory retention, modulation of immune function and metabolism (Zielinski et al., 2016). Sleep difficulties (defined as difficulties initiating and maintaining sleep), inadequate sleep, daytime fatigue, sleepiness and/or irritability, and diagnosed sleep disorders (e.g., insomnia) are endemic in contemporary society (Hillman and Lack, 2013). A recent survey reported the prevalence of sleep difficulties to be 20-35%, in the general population with 5-7% being diagnosed with a sleep disorder (Hillman and Lack, 2013). When sleep is impaired a cascade of acute and chronic mental and physical health conditions may develop, for example, changes in mood and impaired glucose metabolism, both of which are precursors to the development of depression (Riemann and Voderholzer, 2003) and metabolic syndrome (Spiegel et al., 2005) respectively.

The presence of sleep difficulties is a key risk factor for the development and exacerbation of psychiatric symptomatology and the relationship is bidirectional (Abad and Guilleminault, 2005). Sleep difficulties and co-morbid sleep disorders like insomnia are common in individuals with severe mental illness (SMI) (e.g. schizophrenia, schizoaffective disorder, bipolar disorder and major depressive disorder (MDD)) (Buysse et al., 2008; Sivertsen et al., 2009). Up to 90% of patients with any diagnosed mental disorder report abnormal sleep behaviour, including increased sleep onset latency, insomnia or hypersomnia (Breslau et al., 1996; Pigeon et al., 2008). Sleep disorders were incorporated into the Diagnostic Statistical Manual of Mental Disorders in 1987, reflecting their high prevalence and inter-relationship with mental health disorders. Co-morbid sleep disorders are also highly predictive of subsequent development of psychotic illness in individuals who experience at-risk mental states (ARMS) (Poe et al., 2017).

Insomnia is one of the most commonly reported sleep disorders and is characterised by difficulties with initiating sleep, staying asleep and/or experiencing short sleep durations, resulting in poor sleep quality and quantity (Saddichha, 2010). Insomnia has been described as an independent risk factor for developing mental disorders including depression with an odds ratio of 2.10 (CI: 1.86–2.38) (Baglioni et al., 2011; Riemann and Voderholzer, 2003). Sleep can be disrupted for many reasons in people with active mental disorders such as psychosis, depression and anxiety. Symptoms such as paranoia, agitation and ruminations increase arousal, impairing sleep quality (Afonso et al., 2011). Psychotropic medications may impact sleep duration and sleep architecture, decreasing sleep quality (Correll et al., 2011). Additionally, the cognitive decline and neurobiological changes that frequently occur with the development of mental illness can lead to significant disruptions to sleep architecture, sleep quality and circadian rhythmicity (Keshavan et al., 2011; Zanini et al., 2013).

Cardiovascular disease (CVD), metabolic syndrome (MetS) and type 2 diabetes (T2D) are highly prevalent amongst individuals experiencing poor sleep and insomnia (Fatima and Mamun, 2016; Spiegel et al., 2005). In fact, the presence of sleep difficulties appears to be an independent risk factor for the development of metabolic syndrome, irrespective of other lifestyle factors (Chaput, 2011; Troxel et al., 2010). Various mechanisms have been suggested linking poor sleep quality and quantity with an increased risk of cardio-metabolic dysfunction. This includes; the dysregulation of appetite stimulating hormone (ghrelin) and appetite suppressing hormone (leptin) (Taheri et al., 2004); decreased glucose tolerance and insulin sensitivity in response to restrictive sleep (Spiegel et al., 2005) and poor sleep leading to day-time tiredness which results in high levels of sedentary behaviour and reduced physical activity (Klingenberg et al., 2012). Dysregulation of the hypothalamic-pituitary axis, increased sympathetic nervous system activity, and increased inflammation have also been noted as possible mechanisms linking poor sleep and cardiovascular disease (Javaheri and Redline, 2017).

The cardio-metabolic consequences of poor sleep behaviour are of particular concern in populations already at high risk of CVD and MetS, such as people with SMI. People living with SMI have a reduced life-expectancy compared to the general population, primarily as a result of physical health comorbidities, specifically CVD and T2D (Hjorthøj et al., 2017; Tanskanen et al., 2018, Vancampfort et al., 2015). Addressing sleep abnormalities could play major role in the prevention and treatment of cardio-metabolic disease in this high risk population.

Treatment of sleep disorders occurs concurrently with treatment of common psychiatric conditions. For example, current evidence-based treatment for managing the most severe sleep disorders (e.g. insomnia) include psychological and behavioural interventions (e.g. cognitive behavioural therapy and sleep hygiene education) and pharmacotherapy (benzodiazepine and antidepressant medication), the latter typically considered second-line treatment. Both treatment approaches compliment the treatment of mental health symptoms and have substantial effects on improving sleep quality amongst patients with diagnosed sleep disorders (Smith et al., 2002).

Physical activity and the structured, goal-directed subset exercise are effective complementary, non-pharmacological treatments for preventing and managing poor sleep behaviour (Youngsted., 2005, Youngsted & Kline, 2006). Exercise interventions, especially those of a longer duration (≥ 150 minutes/week) and at volumes of moderate-intensities (consistent with current public health guidelines) (Nelson et al, 2007), result in improved self-reported sleep quality, increased sleep duration, increased slow wave sleep and reduced rapid eye-movement sleep (i.e. sleep is longer and deeper and therefore more restful and health-promoting) (King et al., 2008, Driver and Taylor, 2000). A 2015 meta-analysis of studies in the general population found that regular exercise had significant effects on all sleep subscales including; total sleep time, sleep efficiency, sleep onset latency and sleep quality when compared to control groups (Kredlow et al., 2015). This review included a wide range of exercise modalities and intensities ranging from mind/body exercise (e.g. yoga) to more aerobic and resistance-based exercises, all of which were equally beneficial (Kredlow et al., 2015). A recent review specifically evaluated the benefits of resistance exercise (strength training) programs across all aspects of sleep in the general population (Kovacevic et al., 2017) and found that the beneficial effects of exercise on sleep were most evident for sleep quality, with minimal effects on sleep quantity. Such benefits have been found in clinical samples of patients with insomnia (Banno et al., 2018), yet whether targeted exercise interventions can improve sleep quality amongst individuals experiencing SMI has not been previously examined in a systematic review. The aims of the current systematic review were to (a) summarize all available literature regarding the efficacy of exercise interventions in improving sleep quality in individuals with SMI, (b) examine potential moderators including mental health diagnosis, volume and intensity of such interventions, and (c) examine whether improvements in sleep quality are associated with improvements in mental health outcomes.

The current review focuses on the measure of 'sleep quality' as a more comprehensive measure of sleep difficulties, rather than the specific sub-categories of sleep behaviour. It is noted that the reporting of sleep outcomes across various clinical trials is variable, hence for the purposes of our review 'sleep quality' will be the term used to describe the changes in total sleep, being subjective and/or objective.

2. Method

Prior to conducting this systematic review and meta-analysis, the aims and methods were registered with the PROSPERO database (CRD42017077582). Reporting has been conducted as per the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (Moher et al., 2009) (see figure 1).

<Insert figure 1>

2.1 Search Strategy

An electronic database search was conducted from inception to July 2018 using MEDLINE, EMBASE, PsycINFO, Cochrane Central Register of Controlled Trials (CENTRAL), Cumulative Index to Nursing and Allied Health Literature (CINAHL), the Physiotherapy Evidence Database (PEDro), Psychbite, SPORTDiscus, PsychARTICLES and Google Scholar. The search strategy is detailed in Supplementary

Table A. The included studies' reference lists were hand-searched for additional papers which may not have appeared in the electronic search. Titles and/or abstracts of studies retrieved using the search strategy and those from additional sources were screened independently by three authors (OL, RC & CM) to identify studies that potentially met inclusion criteria. The full text of these potentially-eligible studies was retrieved and independently assessed for eligibility by review authors. Reference lists of eligible papers and review articles were manually searched for additional citations. Data were extracted by the primary author (OL), and independently reviewed by another author (SR). Additional searches via google scholar and scanning reference lists of relevant systematic reviews were also undertaken to identify grey literature.

2.2. Inclusion Criteria

Participants.

Studies involving individuals with a DSM or ICD diagnoses (American Psychiatric Association, 2013; Hergueta et al., 1998) of a SMI assessed by diagnostic criteria or defined using a clinically-validated instrument were included. Primarily sub-threshold symptomatology including dysthymia, primary diagnosis of a sleep-disorder (i.e. parasomnia and dyssomnia) and eating disorders were excluded. No restrictions were placed on age, demographics, medication use or physical health co-morbidities.

Interventions.

Any pre-specified 'exercise' intervention was deemed eligible for inclusion. Exercise refers to a structured, formal and premeditated form of physical activity aimed at improving or maintaining physical fitness (Thompson et al., 2003). Examples include aerobic exercise e.g. running, walking, swimming or resistance training. Yoga and tai chi programs were included if the intervention was movement-based. Non-exercise physical activity interventions were excluded; for example, exercise counselling, or lifestyle modification interventions without an active exercise component. Lifestyle interventions that included exercise were included if exercise made up at least 50% of the intervention. Non-movement-based activities e.g. chanting yoga, breathing exercises and mindfulness were excluded. Interventions lasting less than one week were classified as 'acute exercise' and therefore excluded.

Comparison Conditions

Control groups included treatment as usual, sleep intervention only or no-intervention controls. Control groups that included a physical activity component e.g. stretching, game-based activities were not included.

Outcome Measures

The primary outcome was change in sleep quality from baseline to post-exercise intervention. Studies were included if they reported validated subjective and/or objective measures of sleep. Subjective and objective data were independently pooled for analysis. Details of inclusion criteria are provided in figure 2. If multiple follow-up data points were provided, the scores obtained as close to the completion of the most intensive phase of the intervention were utilised. Studies with multiple exercise interventions groups (e.g. aerobic training group vs resistance training group vs control), the exercise or 'active' intervention groups (Herring et al., 2015; Strid et al., 2016) were pooled for analysis as per Cochrane Handbook (table 7.7a) recommendations (Higgins and Green, 2005). For studies reporting separate sleep data for weekends/ weekdays, weekday data were analysed.

<insert figure 2>

Reporting on adverse events as a result of the exercise intervention and cost effectiveness data were also assessed.

If required, the corresponding authors of included trials were contacted to provide additional data for inclusion in the meta-analysis. A follow-up and final email was sent 3 weeks later if corresponding authors did not initially reply. Studies were excluded if authors did not provide the requested data.

Only randomised controlled trials were included in meta-analysis. Quasi-experimental studies were included for purposes of the literature review but were excluded from the analysis. No restriction was placed on the setting or context of the included studies.

2.3 Study quality.

Included studies were assessed for quality using the Physiotherapy Evidence Database Scale (1-10) (PEDro)(Maher et al., 2003), which assesses the internal validity of randomised controlled trials (RCT). The PEDro scale considers key features of RCT's, to provide an overall 'PEDro score' with a PEDro score ≥6 indicating high methodological quality and a PEDro score <6 meaning low methodological quality. PEDro scores for each study included in this review are detailed in Table 2.

2.4 Statistical Analysis.

Comprehensive Meta-Analysis 3.0 was used to perform all analyses. Hedges g scores were calculated using the pre- and post means, standard deviations (SDs) and sample sizes for exercise and control conditions to determine the pooled effect size of primary outcomes. Where raw means were not reported, F-statistics or Cohens d values were used to compute effect size. Effect size direction was coded as positive if the exercise group showed greater improvements in sleep when compared to the control group.

The DerSimonian and Laird random effects model was applied to account for the anticipated heterogeneity between studies. Heterogeneity was assessed with the Cochran Q and I^2 statistic with an $I^2 > 75\%$ indicating high heterogeneity, I^2 between 50% - 75% indicating moderate heterogeneity and an $I^2 < 25\%$ indicating low heterogeneity (Higgins et al., 2003). Begg and Mazumdar Kendall's Tau (Begg and Mazumdar, 1994), Eggers bias test (Egger et al., 1997) and funnel plots were used to assess publication bias. Additionally, we conducted a trim and fill adjusted analysis (Duval and Tweedie, 2000) to recalculate effect size after accounting for the impact of potential publication bias. The classic fail-safe number of observed studies and number of missing studies that would bring p-value to > alpha was also calculated.

Subgroup analyses was performed for the primary outcome of sleep quality to determine if specific moderators impacted the potential efficacy of the intervention. Subgroup analyses on: study quality (PEDro score), mental health diagnosis, setting (inpatient or community), control condition (health education, treatment as usual or waitlist), exercise type (i.e. aerobic, resistance, mixed or mind-body exercise), whether the exercise was individualised or not and qualification of exercise supervisors were performed. An intervention was deemed individualised if the participant had a degree of autonomy over the exercise session and the intensity of the exercise was adjusted to meet the individual's physical capacity.

3. Results

Study Selection and Included Participants

Of the 2816 papers (with duplicates removed) obtained through the electronic database search, 67 full-text articles were assessed for eligibility. Reasons for exclusion are summarised in the PRISMA flowchart (Figure 1). A total of 8 RCT's met study inclusion and were therefore eligible for pooled meta-analysis.

Population

Across all eight studies a total sample of 463 participants with SMI were allocated to an exercise intervention and 736 controls received treatment as usual, waitlist or non-active interventions. Forty one percent of subjects were male and the mean age of participants ranged from 20.0-75.2 years. Diagnosis varied and included studies of individuals with depression (N = 3), substance use disorders (SUD) (N = 2), mixed diagnosis (N = 1), generalised anxiety disorder (GAD) (N = 1) and post-traumatic stress disorder (PTSD) (N = 1). Details are summarised in table 1.

Of the included studies, three studies were conducted in the United States (Field et al., 2013; Lavretsky et al., 2011; Singh et al., 1997), and one in Australia (Rosenbaum et al., 2015), Sweden (Strid et al., 2016), Ireland (Herring et al., 2015), Norway (Flemmen et al., 2014) and Switzerland (Colledge et al., 2017).

Intervention Variables

A diverse range of exercise modalities were employed in the included studies (summarised in table 1). Exercise modalities included; mixed aerobic and resistance exercise (N = 3), aerobic exercise (N = 2), mind-body exercises including tai chi and yoga (N = 2) and resistance exercise (N = 1). The duration of intervention ranged between 6-12 weeks with a mean length of 9.75 weeks. The level of supervision varied between studies with three being supervised but without the level of qualification specified; three supervised by an exercise trainer/ instructor (i.e. yoga/ tai chi instructor) and two supervised by a qualified exercise professional (exercise physiologist/ physiotherapist). Intervention variables including duration, frequency, modality, supervision and control condition are summarized in table 1. Control conditions included; treatment as usual (N = 4), TAU plus health education) (N = 2) and waitlist controls (N = 2). Four studies were considered of low methodological quality (PEDro score of <6) and 4 studies of high quality (PEDro score ≥6) (see table 2).

<Insert table 1>

<Insert table 2>

Adverse Events and Cost Effectiveness

Of the 8 studies, 4 specifically reported adverse events of which no adverse events occurred that were attributed to the interventions. No studies reported on cost.

Sleep Quality Outcome Measures

Eight studies used subjective measures of sleep that included a total or summary score. None of the included studies utilised objective assessments e.g. polysomnography or actigraphy to measure changes in sleep. Of the subjective questionnaires, the Pittsburgh Sleep Quality Index (PSQI) (N = 4) and Insomnia Severity Index (ISI) (N = 2) were the two most frequently used tools with the Karolinska Sleep Questionnaire (KSQ) and Snyder-Halpern R, Verran (1987) subjective sleep questionnaire (SSQ) each used in a single study. Sleep was assessed as a primary outcome in three of the eight included studies (Herring et al, 2015, Singh et al., 1997, Strid et al., 2016).

Pooled random effects calculations found large beneficial effects on overall sleep quality in those participants assigned to exercise when compared with control [hedges g = 0.73, 95 % CI (0.18, 1.28), p=.01; N = 8, n = 1329, I^2 = 91.15%]. Data from eight included studies is summarised in table 3 & figure 3.

<insert table 3>

<insert figure 3>

Both the Begg-Mazumdar Kendall's Tau (0.25, p-value = 0.19) and the Eggers regression tests (bias intercept = 2.16, p-value = 0.17) indicated non-significant publication bias. The trim and fill analysis also found no change to the overall effect size after correcting for potential of publication bias. Fail safe calculations for number of missing studies that would nullify the significance of the main findings was 105.

Subgroup analysis

Subgroup analysis of exercise effects on sleep quality in main analysis are summarised in supplementary table B.

Subgroup analysis of mental health diagnosis found significant improvement in sleep quality in studies of individuals with depression (N = 3, hedges g = 1.83, standard error = 0.85, 95% CI; 0.17-3.49, p-value = 0.03, I^2 = 95.83%). Sub-group analysis for other diagnosis (mixed diagnosis, PTSD, GAD & SUD) were not conducted due to the small number of studies.

Greater improvements were seen in community settings (N = 6, hedges g = 0.833, standard error = 0.349, 95% CI; 0.15-1.52, p-value = 0.02, I^2 = 93.43%) than in inpatient settings (N = 2, hedges g = 0.49, standard error = 0.40, 95% CI; -0.2.98-1.27, p-value = 0.22, I^2 = 55.66%).

As all exercise interventions were performed in supervised settings, we performed a subgroup analysis to determine whether the qualification/ level of training of the supervisor impacted on sleep outcomes. Studies supervised by a qualified exercise professional (such as exercise physiologists), instructor or exercise trainer demonstrated significant improvements in sleep (N = 6, hedges g = 1.003, standard error = 0.440, 95% CI; 0.14-1.87, p-value = 0.02, I^2 = 93.05%) whereas studies conducted by less qualified supervisors (such as research assistants) did not (N = 2, hedges g = 0.16, SE = 0.27, 95% CI = - 0.37 - 0.69, p-value = 0.56, I^2 = 53.78%).

Exercise intensity was not used to perform sub-group analysis as the exercise intensity was not sufficiently described in study protocols. Rather, whether the interventions were tailored/ individualised or not was assessed. Studies that were not individualised displayed greater improvements in sleep (N = 6, hedges g = 0.88, standard error = 0.35, 95% CI; 0.19-1.57, p-value = 0.012) than those studies who allowed individualisation (N = 2, hedges g = 0.31, standard error = 0.53, 95% CI; -0.74-1.35, p-value = 0.56). There was a trend for studies of high methodological quality (PEDro score ≥6) to demonstrate greater improvements in sleep (N = 4, hedges g = 1.30, standard error = 0.72, 95% CI; -0.12-2.72, p-value = 0.07, I^2 = 95%) than those of low methodological quality (N = 4, hedges g = 0.30, standard error = 0.19, 95% CI; -0.08-0.68, p-value = 0.12, I^2 = 71%). Finally, sub-group analysis of control conditions found significant differences between exercise vs ‘health education’ (N = 2, hedges g = 1.28, standard error = 0.22, 95% CI; 0.85-1.71, p-value < 0.00, I^2 = 98%) and ‘treatment as usual’ (N = 4, hedges g = 0.34, standard error = 0.08, 95% CI; 0.19-0.49, p-value < 0.00, I^2 = 48%) and a trend for exercise vs ‘waitlist control’ (N = 2, hedges g = 0.29, standard error = 0.15, 95% CI; -0.01-0.59, p-value = 0.06, I^2 = 90%).

4. Discussion

To our knowledge, this is the first study to systematically review the literature examining the efficacy of exercise to improve sleep quality in individuals with mental illness. We found a large sleep-improving effect for exercise in people living with a mental illness. Compared with current evidence-based treatment for managing sleep disorders like insomnia the efficacy of exercise for improved sleep quality found in this study supports the role of exercise in complementing current treatment practices to further improve the management of poor sleep amongst individuals with mental illness. Compared to current evidence-based treatments, exercise demonstrated comparable efficacy to promoting improvements in sleep amongst people experiencing mental illness. Within the general population, Kredlow et al., (2015) (Kredlow et al., 2015) also found a large beneficial effect on overall sleep quality (Cohen's d = 0.74), suggesting an equally important role for exercise for improving sleep in non-clinical populations and populations with mental illness.

Results of our subgroup analyses indicate that individualised exercise interventions had less of an effect that 'non-individualised' interventions, contradictory to best practise guidelines (Stanton et al., 2015). A possible explanation for this is that only two studies were included in 'individualised exercise' subgroup analysis, Colledge et al., (2017) of patients with SUD and Rosenbaum et al., (2014) of patients with PTSD. Despite Rosenbaum et al., (2014) finding a significant and large effect size (hedges g = 0.80, $p < 0.00$), it is possible that population-specific factors in the Colledge et al., (2017) SUD sample e.g. side effects of withdrawal, may have contributed to the lack of improvements in the 'individualised exercise' sample. Further, subgroup analyses also revealed the sleep-improving benefits of exercise were higher amongst community-based patients compared to inpatients in acute settings. These results suggest patients in the acute phase of a mental illness did not experience as great a benefit as community-based (and hence, presumably, less unwell) patients. Given the limited number of studies included in these subgroup analyses, results should be viewed with caution and as preliminary subgroup analysis. Due to the high degree of heterogeneity between mental health outcome measures and limited number of studies, we were unable to perform a statistical analysis on changes in mental health outcomes and its association with changes in sleep quality. Rather, a detailed review of changes in sleep quality and mental health outcomes in response to the exercise interventions are discussed.

Of the included studies, patients with depression diagnoses demonstrated significant improvements in subjective sleep quality and mood when compared to non-active control groups (independently of modality or intensity of the exercise interventions). For example; in the Field et al., (2013) trial (Field et al., 2013) depressed women in the prenatal period were randomized to 12 weeks of tai chi/ yoga intervention or a waitlist control. Marked improvements in subjective symptoms of depression, anxiety and sleep disturbance were observed in the active intervention group when compared to the control group. The Singh et al., (1997) (Singh et al., 1997) study of older adults with depression adopted a supervised resistance training protocol to determine the effects of exercise on subjective sleep and depressive symptoms (both subjective and clinician assessed). Significant improvements were noted in both sleep quality and depressive symptoms amongst the exercise group when compared to the control group. Interestingly, a strong positive correlation was observed for improved sleep quality and improvements in depressive symptoms. This is consistent with previous studies that have found a strong association between prior insomnia and onset of depression (Johnson et al., 2006). The Lavretsky et al., (2011)(Lavretsky et al., 2011) RCT, also of elderly with depression, compared a 10 week adjunctive tai chi exercise program verse adjective health education classes. Participants randomized to the tai chi group also experienced significantly greater improvements in subjective depression scores and sleep quality compared to the non-active health education group. Results of these studies suggests for patients with depression, simply increasing physical activity levels regardless of the intensity or modality may have equally positive effects on sleep quality and depressive symptoms.

Strid et al., (2016) was the largest study included in this review and the only one to include patients with a primary diagnosis of depression and a range of co-morbid DSM-IV mental illnesses (i.e. Depression, GAD, PTSD, agoraphobia and panic syndrome). Participant diagnosis was predominantly depression (79% in exercise group, 73% in control). For the exercise intervention, participants were randomized to one of three exercise arms (light, moderate or high intensity), the sessions were semi-structured and varied greatly in exercise intensity and modality. Combined, the exercise groups experienced significantly larger positive effects on sleep quality and psychological functioning in comparison to treatment as usual. Results from the Rosenbaum et al., (2015)(Rosenbaum et al., 2015) RCT of patients with post-traumatic stress disorder (PTSD) provides the first evidence that this population may also benefit from the sleep-improving effects of exercise (compared to usual care) in addition to improvements in psychiatric symptomatology. In this 12-week intervention, the exercise group were supervised by an exercise physiologist, the program was structured, individualised and varied in intensity and modality. Finally, the Herring et al., (2015)(Herring et al., 2015) study was the only study in this review specifically observing patients with generalised anxiety disorder (GAD). The protocol consisted of two exercise groups; progressive resistance training (RET) and progressive aerobic training (AET) which were pooled for analysis in the present study. Progressive exercise training improved self-reported sleep outcomes among GAD patients. Significant improvements in sleep were seen in both exercise groups (greater in the RET group) and were associated with reduced symptom severity among GAD patients.

The two studies of patients with a SUD included in this analysis aimed to determine the feasibility and effect of exercise intervention amongst patients. The College et al., (2017)(Colledge et al., 2017) 12 week RCT utilised twice weekly, mixed intensity physical activity sessions for heroin-assisted outpatients with a SUD. Despite being highly feasible (i.e. good adherence), results of the intervention found non-significant improvements in subjective sleep quality, stress levels, depression and substance use variables. Likewise, the Flemmen at al., (2014) (Flemmen et al., 2014) trial, which utilised a high intensity interval training protocol, 3 times per week amongst patients with SUD found no significant between-group differences in subjective sleep quality, anxiety or depression. Possible explanations for the lack of efficacy from these exercise interventions include; small sample sizes and the patient-selected exercise modality and intensity. It must also be considered that for substance use disorders, insomnia presents as an inherent side-effect of withdrawal (Hsu et al., 2012), which may limit the potential sleep-promoting benefits of exercise. Notably, these trails did find significant improvements in physical activity participation and cardiorespiratory fitness, both of which independent risk factors for the development of cardiovascular disease (Vancampfort et al., 2015).

A limitation of the current study is the large heterogeneity between studies including; varying exercise modalities and intensities of exercise, intervention mode of delivery e.g. supervised/ unsupervised, duration of intervention, use of multiple subjective sleep assessments, and different clinical samples. Additionally, the small number of studies representing each clinical group must be considered and conclusions regarding the efficacy of exercise interventions for specific diagnoses require further quality RCTs. Furthermore, the effects of exercise on sleep may be moderated by participant-specific factors including age, comorbidities, time since diagnosis and medication use. Investigation of these factors was not pursued given the small number of studies and limited detail provided within studies.

Of those studies included in this analysis, the exercise protocols in terms of adherence rates, intensity and volume of exercise were poorly described, limiting our investigation of the relative effects of different physical activity interventions. As described in Rosenbaum et al., (2014) (Rosenbaum et al., 2014) a defined exercise intensity would allow for a clearer understanding of the "dose" of exercise required to elicit a therapeutic effect on sleep. However, in light of recent systematic reviews and meta-analysis of exercise interventions in the general population (Kovacevic et al., 2017; Kredlow et al., 2015), it is reasonable to assume that exercise which is supervised, structured and aims to progress in intensity would have greater effects on sleep quality than interventions that are unsupervised and unstructured.

Studies included in this review were limited by the lack of objective measures of sleep quality e.g. accelerometers or polysomnography. Of the subjective sleep tools used, most studies omitted reporting of sleep subscales i.e. sleep quality, sleep efficiency, sleep latency, need for medication, day time dysfunction, amongst others. Further research exploring the effects of exercise on sleep should look at the inclusion of gold-standard objective measures of sleep or at minimum, report individuals' sleep subscales to a) ensure consistency with the broader sleep-research field and b) assist in determining the mechanisms of action of exercise effects so interventions can be better targeted. Practical considerations including the length of the intervention, time of day of exercise prescription and whether exercise programs are tailored to individual fitness level, physical activity history and goals should also be considered in future research. Despite multiple randomised controlled trials of exercise interventions in mental illness, there remains a scarcity of studies, which use validated measures of sleep as a primary or secondary outcome. Given the direct impact of sleep on both physical and mental wellbeing, there is a great need to measure the efficacy of interventions on improving sleep quality. With the increasing focus on lifestyle interventions in mental health care i.e. as seen in the recent Royal Australian and New Zealand College of Psychiatrists (RANZCP) practice guidelines (Galletly et al., 2016), sleep should be considered an important outcome measure for lifestyle interventions. Mental healthcare practitioners must consider the important role exercise plays on improving sleep quality and improving patient's physical and mental wellbeing.

References

Abad, V.C., Guilleminault, C., 2005. Sleep and psychiatry. Dialogues in clinical neuroscience 7(4), 291.
Afonso, P., Brissos, S., Figueira, M.L., Paiva, T., 2011. Schizophrenia patients with predominantly positive symptoms have more disturbed sleep–wake cycles measured by actigraphy. Psychiatry Research 189; 1: 62-66.
Association, A.P., 2013. Diagnostic and statistical manual of mental disorders (DSM-5®). American Psychiatric Pub.
Baglioni, C., Battagliese, G., Feige, B., Spiegelhalder, K., Nissen, C., Voderholzer, U., Lombardo, C., Riemann, D., 2011. Insomnia as a predictor of depression: A meta-analytic evaluation of longitudinal epidemiological studies. Journal of Affective Disorders 135; 1: 10-19.
Banno, M., Harada, Y., Taniguchi, M., Tobita, R., Tsujimoto, H., Tsujimoto, Y., Noda, A., 2018. Exercise can improve sleep quality: a systematic review and meta-analysis. PeerJ; 6: e5172.
Begg, C.B., Mazumdar, M., 1994. Operating characteristics of a rank correlation test for publication bias. Biometrics 50; 4: 1088-1101.
Breslau, N., Roth, T., Rosenthal, L., Andreski, P., 1996. Sleep disturbance and psychiatric disorders: a longitudinal epidemiological study of young adults. Biological Psychiatry 39; 6: 411-418.
Buysse, D.J., Angst, J., Gamma, A., Ajdacic, V., Eich, D., Rössler, W., 2008. Prevalence, Course, and Comorbidity of Insomnia and Depression in Young Adults. Sleep 31; 4: 473-480.
Chaput, J., 2011. Short sleep duration as a cause of obesity: myth or reality? Obesity Reviews 12; 5:e2-3
Chen, M.-Y., Wang, E.K., Jeng, Y.-J., 2006. Adequate sleep among adolescents is positively associated with health status and health-related behaviors. BMC Public Health 6;1: 59.
Colledge, F., Vogel, M., Dürsteler-Macfarland, K., Strom, J., Schoen, S., Pühse, U., Gerber, M., 2017. A pilot randomized trial of exercise as adjunct therapy in a heroin-assisted treatment setting. Journal of Substance Abuse Treatment 76: 49-57.
Correll, C.U., Lencz, T., Malhotra, A.K., 2011. Antipsychotic drugs and obesity. Trends in Molecular Medicine 17; 2: 97-107.
Driver, H.S., Taylor, S.R., 2000. Exercise and sleep. Sleep Medicine Reviews 4; 4: 387-402.
Duval, S., Tweedie, R., 2000. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56; 2: 455-463.
Egger, M., Smith, G.D., Schneider, M., Minder, C., 1997. Bias in meta-analysis detected by a simple, graphical test. British Medical Journal 315; 7109: 629-634.
Fatima, Y., Mamun, A., 2016. Sleep quality and obesity in young subjects: a meta-analysis. Obesity Reviews 17; 11: 1154-1166.
Field, T., Diego, M., Delgado, J., Medina, L., 2013. Tai chi/yoga reduces prenatal depression, anxiety and sleep disturbances. Complementary Therapies in Clinical Practice 19; 1: 6-10.
Flemmen, G., Unhjem, R., Wang, E., 2014. High-intensity interval training in patients with substance use disorder. BioMed Research International.
Galletly, C., Castle, D., Dark, F., Humberstone, V., Jablensky, A., Killackey, E., Kulkarni, J., McGorry, P., Nielssen, O., Tran, N., 2016. Royal Australian and New Zealand College of Psychiatrists clinical practice guidelines for the management of schizophrenia and related disorders. Australian and New Zealand Journal of Psychiatry 50; 5: 410-472.
Hergueta, T., Baker, R., Dunbar, G.C., 1998. The Mini-International Neuropsychiatric Interview (MINI): the development and validation of a structured diagnostic psychiatric interview for DSM-IVand ICD-10. Journal of Clinical Psychiatry 59; Suppl 20: 2233.
Herring, M.P., Kline, C.E., O'Connor, P.J., 2015. Effects of exercise on sleep among young women with Generalized Anxiety Disorder. Mental Health and Physical Activity 9: 59-66.
Higgins, J.P., Green, S., 2005. Cochrane handbook for systematic reviews of interventions.
Higgins, J.P., Thompson, S.G., Deeks, J.J., Altman, D.G., 2003. Measuring inconsistency in meta-analyses. British Medical Journal 327; 7414: 557.

Hillman, D.R., Lack, L.C., 2013. Public health implications of sleep loss: the community burden. The Medical Journal of Australia 199; 8; 7-10.
Hjorthøj, C., Stürup, A.E., McGrath, J.J., Nordentoft, M., 2017. Years of potential life lost and life expectancy in schizophrenia: a systematic review and meta-analysis. The Lancet Psychiatry 4; 4: 295-301.
Hsu, W.Y., Chiu, N.Y., Liu, J.T., Wang, C.H., Chang, T.G., Liao, Y.C., Kuo, P.I., 2012. Sleep quality in heroin addicts under methadone maintenance treatment. Acta neuropsychiatrica 24;6: 356-360.
Javaheri, S., Redline, S., 2017. Insomnia and Risk of Cardiovascular Disease. Chest 152; 2: 435-444.
Johnson, E.O., Roth, T., Breslau, N., 2006. The association of insomnia with anxiety disorders and depression: exploration of the direction of risk. Journal of Psychiatric Research 40;8: 700-708.
Keshavan, M.S., Montrose, D.M., Miewald, J.M., Jindal, R.D., 2011. Sleep correlates of cognition in early course psychotic disorders. Schizophrenia Research 131;1: 231-234.
King, A.C., Pruitt, L.A., Woo, S., Castro, C.M., Ahn, D.K., Vitiello, M.V., Woodward, S.H., Bliwise, D.L., 2008. Effects of moderate-intensity exercise on polysomnographic and subjective sleep quality in older adults with mild to moderate sleep complaints. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63; 9: 997-1004.
Klingenberg, L., Sjödin, A., Holmbäck, U., Astrup, A., Chaput, J.P., 2012. Short sleep duration and its association with energy metabolism. Obesity Reviews 13; 7: 565-577.
Kovacevic, A., Mavros, Y., Heisz, J.J., Fiatarone Singh, M.A., 2017. The effect of resistance exercise on sleep: A systematic review of randomized controlled trials. Sleep Medicine Reviews 39: 52-68
Kredlow, M.A., Capozzoli, M.C., Hearon, B.A., Calkins, A.W., Otto, M.W., 2015. The effects of physical activity on sleep: a meta-analytic review. Journal of Behavioral Medicine 38; 3: 427-449.
Lavretsky, H., Alstein, L.L., Olmstead, R.E., Ercoli, L.M., Riparetti-Brown, M., Cyr, N.S., Irwin, M.R., 2011. Complementary use of tai chi chih augments escitalopram treatment of geriatric depression: a randomized controlled trial. The American Journal of Geriatric Psychiatry 19; 10: 839-850.
Maher, C.G., Sherrington, C., Herbert, R.D., Moseley, A.M., Elkins, M., 2003. Reliability of the PEDro scale for rating quality of randomized controlled trials. Physical Therapy 83; 8: 713-721.
Moher, D., Liberati, A., Tetzlaff, J., Altman, D.G., Group, P., 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. PLoS Medicine 6; 7: e1000097.
Nelson, M.E., Rejeski, W.J., Blair, S.N., Duncan, P.W., Judge, J.O., King, A.C., Macera, C.A., Castaneda-Sceppa, C., 2007. Physical activity and public health in older adults: recommendation from the American College of Sports Medicine and the American Heart Association. Circulation, 116;9: 1094.
Pigeon, W.R., Hegel, M., Unützer, J., Fan, M.-Y., Sateia, M.J., Lyness, J.M., Phillips, C., Perlis, M.L., 2008. Is Insomnia a Perpetuating Factor for Late-Life Depression in the IMPACT Cohort? Sleep 31; 4: 481-488.
Poe, S.-L., Brucato, G., Bruno, N., Arndt, L.Y., Ben-David, S., Gill, K.E., Colibazzi, T., Kantrowitz, J.T., Corcoran, C.M., Girgis, R.R., 2017. Sleep disturbances in individuals at clinical high risk for psychosis. Psychiatry Research 249 (Supplement C): 240-243.
Riemann, D., Voderholzer, U., 2003. Primary insomnia: a risk factor to develop depression? Journal of Affective Disorders 76; 1: 255-259.
Rosenbaum, S., Sherrington, C., Tiedemann, A., 2015. Exercise augmentation compared with usual care for post-traumatic stress disorder: a randomized controlled trial. Acta Psychiatrica Scandinavica 131; 5: 350-359.
Rosenbaum, S., Tiedemann, A., Sherrington, C., Curtis, J., Ward, P.B., 2014. Meta-Analysis Physical Activity Interventions for People With Mental Illness: A Systematic Review and Meta-Analysis. Journal of Clinical Psychiatry 75;0: 1-11.
Saddichha, S., 2010. Diagnosis and treatment of chronic insomnia. Annals of Indian Academy of Neurology 13;2: 94-102.
Singh, N.A., Clements, K.M., Fiatarone, M.A., 1997. A randomized controlled trial of the effect of exercise on sleep. Sleep 20; 2: 95-101.

Sivertsen, B., Krokstad, S., Øverland, S., Mykletun, A., 2009. The epidemiology of insomnia: Associations with physical and mental health.: The HUNT-2 study. Journal of Psychosomatic Research 67; 2: 109-116.
Smith, M.T., Perlis, M.L., Park, A., Smith, M.S., Pennington, J., Giles, D.E., Buysse, D.J., 2002. Comparative meta-analysis of pharmacotherapy and behavior therapy for persistent insomnia. American Journal of Psychiatry 159; 1: 5-11.
Spiegel, K., Knutson, K., Leproult, R., Tasali, E., Cauter, E.V., 2005. Sleep loss: a novel risk factor for insulin resistance and Type 2 diabetes. Journal of Applied Physiology 99; 5: 2008-2019.
Stanton, R., Rosenbaum, S., Kalucy, M., Reaburn, P.,Happell, B., 2015. A call to action: exercise as treatment for patients with mental illness. Australian journal of primary health 21; 2: 120-125.
Strid, C., Andersson, C., Forsell, Y., Öjehagen, A., Lundh, L.G., 2016. Internet-based cognitive behaviour therapy and physical exercise–Effects studied by automated telephone assessments in mental ill-health patients; a randomized controlled trial. British Journal of Clinical Psychology 55; 4: 414-428.
Taheri, S., Lin, L., Austin, D., Young, T., Mignot, E., 2004. Short sleep duration is associated with reduced leptin, elevated ghrelin, and increased body mass index. PLoS medicine 1; 3: e62.
Tanskanen, A., Tiihonen, J. and Taipale, H., 2018. Mortality in schizophrenia: 30-year nationwide follow-up study. Acta Psychiatrica Scandinavica.
Thompson, P.D., Buchner, D., Piña, I.L., Balady, G.J., Williams, M.A., Marcus, B.H., Berra, K., Blair, S.N., Costa, F., Franklin, B., 2003. Exercise and physical activity in the prevention and treatment of atherosclerotic cardiovascular disease. Circulation 107; 24: 3109-3116.
Troxel, W.M., Buysse, D.J., Matthews, K.A., Kip, K.E., Strollo, P.J., Hall, M., Drumheller, O., Reis, S.E., 2010. Sleep Symptoms Predict the Development of the Metabolic Syndrome. Sleep 33; 12: 1633-1640.
Vancampfort, D., Stubbs, B., Mitchell, A.J., De Hert, M., Wampers, M., Ward, P.B., Rosenbaum, S., Correll, C.U., 2015. Risk of metabolic syndrome and its components in people with schizophrenia and related psychotic disorders, bipolar disorder and major depressive disorder: a systematic review and meta-analysis. World Psychiatry 14;3: 339-347.
Youngstedt, S.D., 2005. Effects of exercise on sleep. Clinics in sports medicine, 24; 2: 355-365.
Youngstedt, S.D. and Kline, C.E., 2006. Epidemiology of exercise and sleep. Sleep and biological rhythms, 4; 3: 215-221.
Zanini, M., Castro, J., Coelho, F.M., Bittencourt, L., Bressan, R.A., Tufik, S., Brietzke, E., 2013. Do sleep abnormalities and misaligned sleep/circadian rhythm patterns represent early clinical characteristics for developing psychosis in high risk populations? Neuroscience & Biobehavioral Reviews 37; 10, Part 2: 2631-2637.
Zielinski, M.R., McKenna, J.T., McCarley, R.W., 2016. Functions and Mechanisms of Sleep. AIMS Neuroscience 3; 1: 67.

Tables and figures

Figure 1. PRISMA 2009 Flow Diagram

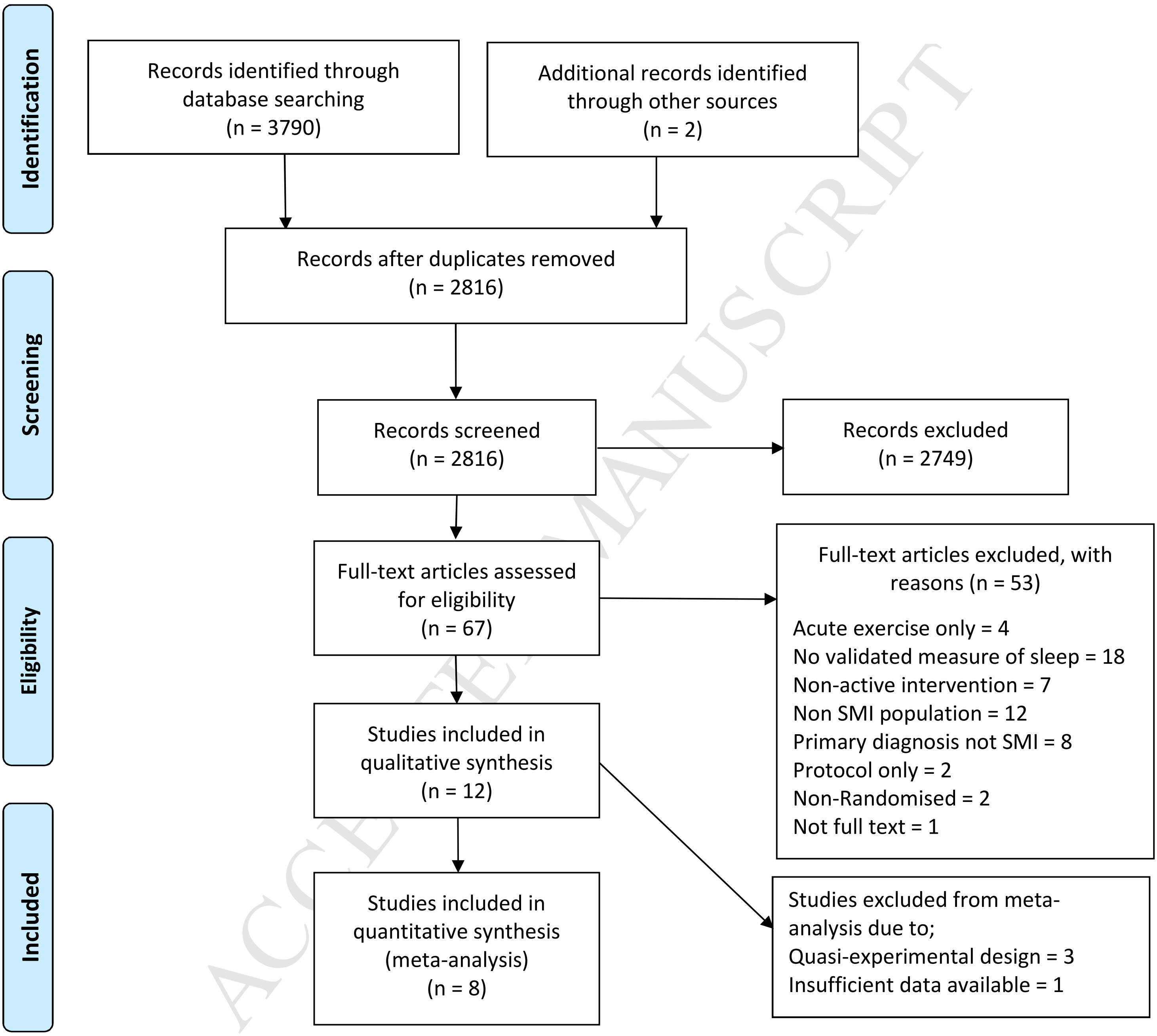


Table 1. Exercise interventions included in meta-analysis

Figure 2. Inclusion criteria

Design
- Randomized controlled trials and quasi-experimental studies

Participants
- No restrictions on age, gender, socio-economic status or geographic location
- Primary diagnosis of DSM, ICD or other diagnosis of a mental illness (including substance use disorders).

Interventions
- Structured exercise program
- Lifestyle interventions in which physical exercise was at least 50% of total intervention
- Tai Chi, physical yoga

Outcome measures
- Total subjective sleep score defined as 'sleep quality'
- Sleep quality sub-score – only used in absence of a 'total subjective sleep score'
- Sleep duration sub-score - only used in absence of a 'total subjective sleep score'
- Sleep efficiency – sub-score - only used in absence of a 'total subjective sleep score'
- Polysomography scores
- Actigraphy scores

Comparisons
- Exercise program versus usual care
- Exercise program versus wait-list
- Exercise program versus health education (including talking therapy, games etc.)

	Sample characteristics					Exercise Intervention					
	Exercise n=	Control n=	Mean age (SD)	% male	Diagnosis; diagnostic criteria	Session content	Setting	Supervision	Weeks + Sessions	Comparator	Sleep outcomes
Colledge et al., 2017	a) 13	b) 11	a) 42.7 (6.5) b) 45.8 (4.2)	63	SUD (ICD-10)	Moderate to vigorous physical activity (including climbing, badminton, strength training, boxing and dance). Light walking was also offered as an alternative	Community	Trained study personnel with a background in sports education.	12 weeks, 2 days/ week (duration unspecified)	Treatment as usual - Other activities group e.g. cooking, board games, painting etc.	Insomnia Severity Index (ISI)
Field et al. 2013	a) 37	b) 38	a) 24.4 (4.7) b) 26 (5.6)	0	MDD, dysthymia (SCID, DSM-IV)	Combined yoga/ tai chi routine	Community	Trained yoga instructor	12 weeks, 1 x 20 mins	Waitlist control	Snyder-Halpern R, Verran (1987) subjective sleep questionnaire
Flemmen et al. 2014	a) 9	b) 7	a) 33 (11) b) 31 (8)	81	SUD (ICD-10)	a) Aerobic interval training – inclined walking or running on treadmill 4 x 4min at 90–95% of HRmax with 3-minute interval recoveries at 70% of HRmax	Residential inpatient	Supervised, exercise professional	8-week, 3 x 30 mins	b) Treatment as usual	Insomnia Severity Index (ISI)
Herring et al. 2015	a) 8 b) 8	7	23.9 (6.2)	0	GAD (DSM-IV)	a) Progressive resistance training – 7 sets, 10 reps of 3 lower limb exercise b) Progressive aerobic	Community	Supervised, qualification not specified	6 weeks, 2 x 30 mins	Waitlist control	The Pittsburgh Sleep Quality Index (PSQI)

						training					
Lavretsky et al. 2011	a) 36	b) 37	a) 69.1 (7.0) b) 72.0 (7.4)	38	MDD, (DSM-IV)	a) Tai Chi + SSRI	Community	Tai Chi instructor	10 weeks, 1 x 2-hour session/ week	b) TAU + health education group	The Pittsburgh Sleep Quality Index (PSQI)
Rosenbaum et al., 2015	a) 39	b) 42	a) 47.1 (11.3) b) 52.0 (12.7)	84	PTSD, (DSM-IV-TR)	a) Progressive resistance-training and a pedometer-based walking programme	In-patient	Exercise Physiologist	12 weeks, 3 days/week, 30 mins	b) Treatment as usual care (non-active intervention)	The Pittsburgh Sleep Quality Index (PSQI)
Singh et al., 1997	a) 15	b) 13	a) 70 (1.6) b) 72 (1.9)	39	Unipolar minor or major depression or dysthymia, (DSM-IV)	a) Progressive resistance training, 80% of 1RM Groups of 1-8	Community	Supervised, qualification not specified	10 weeks, 3 days/ week, 60 mins	b) TAU + health education group	The Pittsburgh Sleep Quality Index (PSQI) Likert Sleep quality scale
Strid et al. 2016*	a) 298	b) 302 C) 279	a) 42.0 (12.2) b) 43.5 (12.3) c) 43.0 (12.2)	26	Depression spectrum disorders MADRS (comorbid, GAD, PTSD, agoraphobia, panic syndrome) (M.I.N.I)	a) Mixed modalities; 1. Low intensity (yoga or Pilates), 2. Moderate intensity (aerobics), 3. High intensity (spinning or aerobics)	Community	Semi-supervised, qualification not specified	12 weeks, 3 hours/ week	b) Internet CBT C) Treatment as usual	The Karolinska Sleep Questionnaire (KSQ),

Notes:
MDD, Major Depressive Disorder
DSM-IV, Diagnostic Statistical Manual of Mental Disorders version 4
SCID, Structured Clinical Interview for DSM
BDI, Beck depression inventory
ICD-10, International Classification of Diseases, Classification of Mental and Behavioural Disorders
ICDS, International classification of sleep disorders
MARDS, Montgomery–Asberg Depression Rating Scale

GAD, Generalised Anxiety Disorder
SUD, Substance Use Disorder
$HR_{max,}$ Maximum heart rate
RM, Repetition Maximum
*Participants in the Strid et al., (2016) study were assessed as having 'mild-to-moderate' depression on the basis of the self-report version of the MADRS, which provides an indication of MDD. Although not a diagnostic instrument, MADRS items overlap with DSM-V criteria for depression and was therefore included for analysis.

Table 2. Methodological quality of included trials for primary meta-analysis based of PEDro scoring system (n=8)

Trial	PEDro Score	Eligibility criteria specified	Random allocation	Concealed allocation to groups	Baseline comparability	Blinding of all subjects	Blinding of therapists who administered therapy	Blinding assessment of outcome measures	Adequate follow-up	Intention to treat analysis	Between-group statistic al comparisons reported	Both point measures and measures of variability reported
Colledge et al., 2017 n = 13	6	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	Yes
Field et al. 2013 n = 37	4	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes
Flemmen et al. 2014 n = 9	5	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes
Herring et al. 2015 n = 16	4	No	Yes	No	Yes	No	No	No	No	No	Yes	Yes
Lavretsky et al. 2011 n = 36	8	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes
Rosenbaum et al., 2015 n = 39	7	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes	Yes	Yes
Singh et al., 1997 n = 15	6	Yes	Yes	No	Yes	No	No	Yes	Yes	No	Yes	Yes
Strid et al. 2016 n = 298	5	Yes	Yes	No	Yes	No	No	No	No	Yes	Yes	Yes

[a]*PEDro score* ≥6 high methodological quality; PEDro score <6 low methodological quality

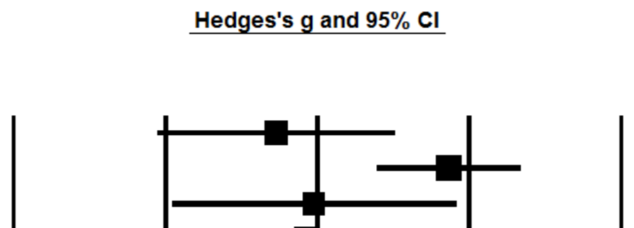
Table 3. Main analysis of exercise effect on sleep quality outcomes

Study name	Exercise type	Population	Outcome	RCT model	Statistics for each study						
					Hedges's	Standar	Varianc	Lower	Upper	Z-	p-

					g	d error	e	limit	limit	Value	Value
Colledge, 2017	Mixed	SUD	ISI	Ex vs TAU	-0.27	0.40	0.16	-1.05	0.51	-0.67	0.50
Field, 2013	Yoga/ Tai Chi	Depression	SSQ	Ex vs TAU	0.87	0.24	0.06	0.40	1.34	3.63	0.00
Flemmen, 2014	Aerobic	SUD	ISI	Ex vs TAU	-0.02	0.48	0.23	-0.95	0.92	-0.04	0.97
Herring, 2015	Mixed	GAD	Combined	Ex vs TAU	-0.11	0.20	0.04	-0.51	0.28	-0.56	0.57
Lavretsky, 2011	Tai Chi	Depression	PSQI (total)	Ex vs TAU (plus health education)	0.54	0.24	0.06	0.06	1.02	2.21	0.03
Rosenbaum, 2015	Mixed	PTSD	PSQI (total)	Ex vs TAU	0.80	0.27	0.07	0.28	1.33	2.98	0.00
Singh, 1997	Resistance	Depression	Combined	Ex vs TAU (plus health education)	4.29	0.49	0.24	3.32	5.26	8.68	0.00
Strid, 2016	Mixed	Mixed Dx	KSQ	Ex vs TAU	0.33	0.08	0.01	0.17	0.50	3.95	0.00
Total					0.73	0.28	0.08	0.18	1.28	2.59	0.01

Meta-analysis of exercise effects on sleep quality in comparison to control conditions.
Ex = Exercise
TAU = Treatment As Usual
PSQI = Pittsburgh Sleep Quality Index
ISI = Insomnia Severity Index
KSQ = Karolinska Sleep Questionnaire
Dx = diagnosis
SUD = Substance Use Disorder

Figure 3. Forest plot of main analysis



Supplementary material

Supplementary Table A. Search strategy (term or combination of terms followed by number of articles returned)

1	exercise.mp.	822287
2	exercise.mp.	822287
3	physical exertion.mp.	64177
4	swimming.mp.	73575
5	jogging.mp.	5003
6	running.mp.	146765
7	bicycling.mp.	14346
8	resistance training.mp.	29956
9	aerobic training.mp.	6142
10	physical activity.mp.	288309
11	walking.mp.	202006
12	2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11	1342549
13	intervention.mp.	1521844
14	randomized.mp.	2107706
15	randomised.mp.	297693
16	controlled trial.mp.	1379206
17	control group.mp.	966568
18	clinical trial.mp.	2243514
19	control groups.mp.	183945
20	prospective.mp.	1673074
21	13 or 14 or 15 or 16 or 17 or 18 or 19 or 20	6416920
22	mental disorder*.mp.	376221
23	severe mental.mp.	26222
24	serious mental.mp.	13916
25	depression.mp.	1207401
26	depressive.mp.	395048
27	bipolar.mp.	205866
28	post traumatic.mp.	95363
29	psychotic.mp.	147823
30	psychosis.mp.	193706
31	schizophr*.mp.	445671
32	antipsychotic*.mp.	152580
33	antidepressant*.mp.	240860
34	anxiety.mp.	706456
35	obsessive compulsive.mp.	69109
36	panic.mp.	58489

37	ADHD.mp.	76129
38	sleep*.mp.	522375
39	circadian.mp.	187525
40	REM.mp.	59938
41	parasomnia.mp.	5967
42	arousal disorder*.mp.	2761
43	hypersomnia.mp.	6726
44	insomnia.mp.	93724
45	38 or 39 or 40 or 41 or 42 or 43 or 44	723051
46	22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34 or 35 or 36 or 37	2770898
47	12 and 21 and 45 and 46	3665
48	12 and 21 and 45 and 46	3665
49	eating disorder*.mp.	82659
50	anorexia.mp.	125822
51	46 or 49 or 50	2908232
52	12 and 21 and 45 and 51	3790
53	remove duplicates from 52	2811

Supplementary Table B. Sub-group analysis of included trials

Analysis	Number of RCTs	Meta-analysis					Heterogeneity		
		Point estimate of effect size (hedges g)	Variance	95% CI		P value (test of null, 2-tailed)	I^2 (%)	Q-value	P value
Study quality									
High (PEDro ≥6)	4	1.30	0.52	-0.12	2.72	0.07	94.83	58.00	0.00
Low (PEDro <6)	4	0.30	0.04	-0.08	0.68	0.12	71.12	10.40	0.02
Diagnosis									
Depression	3	1.83	0.72	0.17	3.49	**0.03**	95.83	47.92	0.00
Other (GAD, Mixed Dx, PTSD)	3	0.31	0.04	-0.09	0.71	0.13	74.49	7.84	0.02
SUD	2	-0.17	0.09	-0.76	0.43	0.59	0.00	0.16	0.69
Study setting									
Community	6	0.83	0.13	0.15	1.55	**0.02**	93.43	76.13	0.00
Inpatient	2	0.49	0.16	-0.30	1.27	0.22	55.65	2.26	0.13
Exercise Type									
Aerobic	2	0.32	0.01	0.16	0.48	**0.00**	0.00	0.52	0.47
Mind-body	2	0.17	0.03	0.37	1.04	**0.00**	0.00	0.93	0.34
Mixed	3	0.16	0.11	-0.50	0.82	0.63	76.96	8.70	0.01
Resistance	1	4.29	0.24	3.32	5.26	**0.00**	0.00	0.00	1.00
Control condition									
Exercise vs health education	2	1.28	0.05	0.85	1.71	**0.00**	97.84	46.34	0.00
Exercise vs TAU	4	0.34	0.01	0.19	0.49	**0.00**	48.80	5.86	0.12
Exercise vs waitlist	2	0.42	0.02	-0.01	0.59	0.06	89.84	9.84	0.00
Individualised vs structured									
Individualised	2	0.31	0.29	-0.74	1.35	0.56	79.85	4.96	0.03
Not Individualised	6	0.88	0.12	0.19	1.57	**0.01**	93.25	74.07	0.00
Professional who supervised									
Qualified exercise professional/ instructor/ exercise trainer	6	1.00	0.19	0.14	1.87	**0.02**	93.05	71.92	0.00
Other	2	0.16	0.07	-0.37	0.69	0.56	53.77	2.16	0.14

The analyses conducted in this table were undertaken using the DerSimonian and Laird method with a random effects model.